JC05 Rec'd PCT/PTO 08 APR 2002

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(REV 12-2001)

U S DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371

ATTORNEY'S DOCKET NUMBER
6770-8

U S. APPLICATION NO (If known, see 37 CFR 1 5
10/089978

INTERNATIONAL APPLICATION NO.	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED
PCT/EP00/100 22	10 October 2000	11 October 1999

TITLE OF INVENTION
Torque Measurement Apparatus

APPLICANT(S) FOR DO/EO/US
~~FAST Technology AG~~ AXEL LUTZ MAY.

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☐ This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include items (5), (6), (9) and (21) indicated below.
4. ☐ The US has been elected by the expiration of 19 months from the priority date (Article 31).
5. ☒ A copy of the International Application as filed (35 U.S.C. 371(c)(2))
   - a. ☒ is attached hereto (required only if not communicated by the International Bureau).
   - b. ☐ has been communicated by the International Bureau.
   - c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☐ An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).
   - a. ☐ is attached hereto.
   - b. ☐ has been previously submitted under 35 U.S.C. 154(d)(4).
7. ☒ Amendments to the claims of the International Aplication under PCT Article 19 (35 U.S.C. 371(c)(3))
   - a. ☐ are attached hereto (required only if not communicated by the International Bureau).
   - b. ☒ have been communicated by the International Bureau.
   - c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   - d. ☐ have not been made and will not be made.
8. ☐ An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371 (c)(3)).
9. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)). UNSIGNED
10. ☐ An English lanugage translation of the annexes of the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11 to 20 below concern document(s) or information included:

11. ☐ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
12. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. ☒ A FIRST preliminary amendment. (11 pgs)
14. ☐ A SECOND or SUBSEQUENT preliminary amendment.
15. ☐ A substitute specification.
16. ☐ A change of power of attorney and/or address letter.
17. ☐ A computer-readable form of the sequence listing in accordance with PCT Rule 13ter.2 and 35 U.S.C. 1.821 - 1.825.
18. ☐ A second copy of the published international application under 35 U.S.C. 154(d)(4).
19. ☐ A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4).
20. ☒ Other items or information:
    Published International Application with Search Report (22 pgs.)
    International Preliminary Examination Report (claims 1-6) (8 pgs.)
    One (1) Notification of Recording of A Change (1 pg.)
    Unsigned Declaration and Power of Attorney (2 pgs.)

JC15 Rec'd PCT/PTO 08 APR 2002

U.S. APPLICATION NO. (if known, see 37 CFR 1.5) 10/089978	INTERNATIONAL APPLICATION NO	ATTORNEY'S DOCKET NUMBER

	CALCULATIONS	PTO USE ONLY
21. [X] The following fees are submitted: **BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)):** Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO . . . . **$1040.00** International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO . . . . **$890.00** International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO . . . . **$740.00** International preliminary examination fee (37 CFR 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4) . . . . **$710.00** International preliminary examination fee (37 CFR 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4) **$100.00**		
ENTER APPROPRIATE BASIC FEE AMOUNT =	$ 890.00	
Surcharge of **$130.00** for furnishing the oath or declaration later than [ ] 20 [ ] 30 months from the earliest claimed priority date (37 CFR 1.492(e)).	$ 130.00	

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE	$	
Total claims	13 - 20 =	0	x **$18.00**	$	
Independent claims	4 - 3 =	1	x **$84.00**	$ 84.00	
MULTIPLE DEPENDENT CLAIM(S) (if applicable)			+ **$280.00**	$	
TOTAL OF ABOVE CALCULATIONS =				$ 1104.00	
[X] Applicant claims small entity status. See 37 CFR 1.27. The fees indicated above are reduced by 1/2.				$ 552.00	
SUBTOTAL =				$ 552.00	
Processing fee of **$130.00** for furnishing the English translation later than [ ] 20 [ ] 30 months from the earliest claimed priority date (37 CFR 1.492(f)).				$	
TOTAL NATIONAL FEE =				$ 552.00	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). **$40.00** per property +				$	
TOTAL FEES ENCLOSED =				$ 552.00	
				Amount to be refunded:	$
				charged:	$

a. [ ] A check in the amount of $ ________ to cover the above fees is enclosed.

b. [ ] Please charge my Deposit Account No. ________ in the amount of $ ______ to cover the above fees. A duplicate copy of this sheet is enclosed.

c. [X] The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 03-1231 . A duplicate copy of this sheet is enclosed.

d. [X] Fees are to be charged to a credit card. **WARNING:** Information on this form may become public. **Credit card information should not be included on this form.** Provide credit card information and authorization on PTO-2038.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137 (a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

Robert C. Kain, Jr.
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SIGNATURE

Robert C. Kain, Jr.
NAME

30,648
REGISTRATION NUMBER

10/089978

JC15 Rec'd PCT/PTO 08 APR 2002

PATENTS

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of LUTZ AXEL MAY

Serial No.

Filed:

For: TORQUE MEASUREMENT APPARATUS

PRELIMINARY AMENDMENT

Assistant Commissioner for Patents
Washington, D.C. 20231
Box PCT Application

Sir:

Please enter this amendment prior to calculating the filing fee for this case.

IN THE CLAIMS

A marked-up version of the claims is attached as Exhibit A hereto.

A clean version of the claims follows:

1.(Amended) A torque transducer for measuring torque in a rotating shaft of the kind having a transducer region, for example a region storing a permanent magnetisation, in which a magnetic transducer field is established and at least one non-contacting sensor adjacent the transducer region to develop a torque-dependent signal, wherein in operation the shaft is subject to longitudinal flux generated by means external to the transducer region, characterised by a non-contacting sensor responsive to a component of said longitudinal flux to develop a signal representing the level of said longitudinal flux, and means responsive to the level-representing signal for said longitudinal flux and magnetically coupled to said shaft to generate a compensating flux to counteract said

longitudinal flux at the transducer region.

2.(Amended) A torque transducer as claimed in Claim 1 wherein said means for generating the compensating flux comprises at least one current-carrying coil about the shaft to be magnetically coupled thereto.

3. (Amended) A torque transducer as claimed in Claim 1 said means for generating the compensating flux comprises a magnetic structure having poles spaced along the shaft and at least one current-carrying coil wound on said magnetic structure.

4. (Amended) A torque transducer as claimed in Claim 1 in which said shaft carries a collar structure comprising two axially-spaced portions in the space between which is disposed the sensor responsive to the component of longitudinal flux.

5. (Amended) A torque transducer for measuring the torque in a rotating shaft which, in operation, has a longitudinal field extending therealong, wherein at least one sensor is placed in non-contacting fashion adjacent a portion of the shaft to sense and provide a signal dependent on a transverse component of flux arising from the longitudinal flux due to the torque in the shaft.

6. (Amended) A torque transducer as claimed in Claim 5 in which a further non-contacting sensor is mounted to sense the longitudinal flux to provide a reference signal.

7. (Amended) A torque transducer for a rotating shaft comprising flux generating means for generating a magnetic flux extending longitudinally in a portion of the shaft, said flux generating means being magnetically coupled to said shaft at axially spaced locations between which said portion is situated, at least one sensor placed in non-contacting fashion adjacent said portion to provide a signal dependent on a transverse component of flux arising from the longitudinal flux in said portion due to the torque in the shaft,

said magnetic flux generating means being operable to generate an alternating magnetic field at a selected frequency, and said at least one sensor signal being processed by frequency selective means operable at said selected frequency to provide a signal representing torque in the shaft derived from said alternating magnetic field.

8. (Amended) A torque transducer as claimed in claim 7 in which said shaft transmits in operation another longitudinal flux, not generated by said flux generating means said selected frequency enabling the signal dependent on the transverse component of flux to be separated from any signal due to said other longitudinal flux in processing by said frequency selective means.

9. A torque transducer as claimed in Claim 8 in which said flux generating means operates in a pulsed mode.

10. (Amended) A torque transducer element as claimed in Claim 7 in which said flux generating means comprises a pair of spaced coils wound about said shaft and between which said portion is situated and means for energising said coils at the selected frequency.

11.(Amended) A torque transducer element as claimed in Claim 7 in which said flux generating means comprises a magnetic structure having a pair of spaced poles which magnetically coupled to said shaft and between which said portion is situate, at least one coil would on said magnetic structure, and means for energising said at least one coil at the selected frequency.

12. (Amended) A transducer assembly for measuring, preferably in a non-contacting fashion, torque in a rotating shaft, the assembly comprising an erase head for cleaning a zone of the shaft as it rotates, a write head downstream of the erase head in the direction of rotation to write a magnetic track of a given width onto the cleaned zone, a pair of read heads spaced in an axial direction to respond to the magnetic track, said read heads being disposed on, toward or adjacent

opposite sides of the track to generate respective signals, and differential means response to said respective signals to provide a signal dependent on the torque in the shaft.

13. (Amended) A transducer assembly as claimed in Claim 12 in which said write head is energised with an AC signal at a selected frequency.

Remarks

Please enter this amendment prior to calculating the filing fee. A marked-up version of the claims 1- 6 as presented in the International Preliminary Examination Report and original claims 7 - 13 in the published PCT application is attached as Exhibit A. Exhibit B is a clean version of the claims.

Respectfully submitted,

Fleit, Kain, Gibbons, Gutman & Bongini, PL

By____________________________

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Exhibit A - Marked Claims

1. (Am'd) A torque transducer for measuring torque in a rotating shaft ~~(61)~~ of the kind having a transducer region ~~(64)~~, for example a region storing a permanent magnetisation, in which a magnetic transducer field is established and at least one non-contacting sensor ~~(7; 22; 23)~~ adjacent the transducer region ~~(64)~~ to develop a torque-dependent signal, wherein in operation the shaft ~~(61)~~ is subject to longitudinal flux ~~(60)~~ generated by means ~~(63)~~ external to the transducer region ~~(64)~~, characterised by a non-contacting sensor ~~(97; 21; 24)~~ responsive to a component of said longitudinal flux to develop a signal representing the level of said longitudinal flux, and means ~~(65)~~ responsive to the level-representing signal for said longitudinal flux and magnetically coupled to said shaft ~~(61)~~ to generate a compensating flux to counteract said longitudinal flux at the transducer region ~~(64)~~.

2. (Amd) A torque transducer as claimed in Claim 1 wherein said means for generating the compensating flux comprises at least one current-carrying coil ~~(L1, L2)~~ about the shaft to be magnetically coupled thereto.

3. (Amd) A torque transducer as claimed in Claim 1 said means ~~(65)~~ for generating the compensating flux comprises a magnetic structure ~~(70)~~ having poles ~~(72a, 72b)~~ spaced along the shaft ~~(61)~~ and at least one current-carrying coil ~~(L3, L4)~~ wound on said magnetic structure ~~(70)~~.

4. (Amd) A torque transducer as claimed in Claim 1~~, 2 or 3~~ in which said shaft carries a collar structure ~~(20)~~ comprising two axially-spaced portions in the space ~~(25)~~ between which is disposed the sensor ~~(24)~~ responsive to the component of longitudinal flux.

5. (Amd) A torque transducer for measuring the torque in a rotating shaft ~~(61)~~ which, in operation, has a longitudinal field ~~(60)~~ extending therealong, wherein at least one sensor ~~(25)~~ is placed in non-contacting fashion adjacent a portion of the shaft to sense and provide a signal

dependent on a transverse component of flux arising from the longitudinal flux due to the torque in the shaft ~~(61)~~.

6. (Amd) A torque transducer as claimed in Claim 5 in which a further non-contacting sensor ~~(24)~~ is mounted to sense the longitudinal flux to provide a reference signal.

7. (Amd) A torque transducer for a rotating shaft ~~(61)~~ comprising flux generating means ~~(L1, L2)~~ for generating a magnetic flux extending longitudinally in a portion ~~(64)~~ of the shaft, said flux generating means ~~(L1, L2)~~ being magnetically coupled to said shaft at axially spaced locations between which said portion ~~(64)~~ is situated, at least one sensor ~~(25)~~ placed in non-contacting fashion adjacent said portion to provide a signal dependent on a transverse component of flux arising from the longitudinal flux in said portion ~~(64)~~ due to the torque in the shaft ~~(61)~~,

said magnetic flux generating means being operable to generate an alternating magnetic field at a selected frequency, and said at least one sensor signal being processed by frequency selective means ~~(24)~~ operable at said selected frequency to provide a signal representing torque in the shaft ~~(61)~~ derived from said alternating magnetic field.

8. (Amd) A torque transducer as claimed in claim 7 in which said shaft ~~(61)~~ transmits in operation another longitudinal flux ~~(60)~~, not generated by said flux generating means ~~(L1, L2. L3, L4)~~ said selected frequency enabling the signal dependent on the transverse component of flux to be separated from any signal due to said other longitudinal flux in processing by said frequency selective means ~~(34)~~.

9. A torque transducer as claimed in Claim 8 in which said flux generating means operates in a pulsed mode.

10. (Amd) A torque transducer element as claimed in Claim 7~~, 8 or 9~~ in which said flux generating means comprises a pair of spaced coils ~~(L1, L2)~~ wound about said shaft ~~(61)~~ and between which said portion ~~(64)~~ is situated and means ~~(20)~~ for energising said coils ~~(L1, L2)~~ at the selected frequency.

11. (Amd) A torque transducer element as claimed in Claim 7~~, 8 or 9~~ in which said flux generating means comprises a magnetic structure ~~(70)~~ having a pair of spaced poles ~~(72a, 72b)~~ which magnetically coupled to said shaft ~~(61)~~ and between which said portion ~~(64)~~ is situate, at least one coil ~~(L3, L4)~~ would on said magnetic structure, and means ~~(20)~~ for energising said at least one coil ~~(L3, L4)~~ at the selected frequency.

12. (Amd) A transducer assembly for measuring, preferably in a non-contacting fashion, torque in a rotating shaft ~~(61)~~, the assembly comprising an erase head ~~(12)~~ for cleaning a zone ~~(16)~~ of the shaft as it rotates, a write head ~~(14)~~ downstream of the erase head ~~(12)~~ in the direction of rotation to write a magnetic track ~~(15)~~ of a given width onto the cleaned zone ~~(16)~~, a pair of read heads ~~(14a, 14b)~~ spaced in an axial direction to respond to the magnetic track ~~(15)~~, said read heads ~~(14a, 14b)~~ being disposed on, toward or adjacent opposite sides of the track ~~(15)~~ to generate respective signals, and differential means response to said respective signals to provide a signal dependent on the torque in the shaft ~~(61)~~.

13. (Amd) A transducer assembly as claimed in Claim 12 in which said write head ~~(15)~~ is energised with an AC signal at a selected frequency.

Exhibit B - Clean Claims

1.(Amended) A torque transducer for measuring torque in a rotating shaft of the kind having a transducer region, for example a region storing a permanent magnetisation, in which a magnetic transducer field is established and at least one non-contacting sensor adjacent the transducer region to develop a torque-dependent signal, wherein in operation the shaft is subject to longitudinal flux generated by means external to the transducer region, characterised by a non-contacting sensor responsive to a component of said longitudinal flux to develop a signal representing the level of said longitudinal flux, and means responsive to the level-representing signal for said longitudinal flux and magnetically coupled to said shaft to generate a compensating flux to counteract said longitudinal flux at the transducer region.

2.(Amended) A torque transducer as claimed in Claim 1 wherein said means for generating the compensating flux comprises at least one current-carrying coil about the shaft to be magnetically coupled thereto.

3. (Amended) A torque transducer as claimed in Claim 1 said means for generating the compensating flux comprises a magnetic structure having poles spaced along the shaft and at least one current-carrying coil wound on said magnetic structure.

4. (Amended) A torque transducer as claimed in Claim 1 in which said shaft carries a collar structure comprising two axially-spaced portions in the space between which is disposed the sensor responsive to the component of longitudinal flux.

5. (Amended) A torque transducer for measuring the torque in a rotating shaft which, in operation, has a longitudinal field extending therealong, wherein at least one sensor is placed in non-

contacting fashion adjacent a portion of the shaft to sense and provide a signal dependent on a transverse component of flux arising from the longitudinal flux due to the torque in the shaft.

6. (Amended) A torque transducer as claimed in Claim 5 in which a further non-contacting sensor is mounted to sense the longitudinal flux to provide a reference signal.

7. (Amended) A torque transducer for a rotating shaft comprising flux generating means for generating a magnetic flux extending longitudinally in a portion of the shaft, said flux generating means being magnetically coupled to said shaft at axially spaced locations between which said portion is situated, at least one sensor placed in non-contacting fashion adjacent said portion to provide a signal dependent on a transverse component of flux arising from the longitudinal flux in said portion due to the torque in the shaft,

said magnetic flux generating means being operable to generate an alternating magnetic field at a selected frequency, and said at least one sensor signal being processed by frequency selective means operable at said selected frequency to provide a signal representing torque in the shaft derived from said alternating magnetic field.

8. (Amended) A torque transducer as claimed in claim 7 in which said shaft transmits in operation another longitudinal flux, not generated by said flux generating means said selected frequency enabling the signal dependent on the transverse component of flux to be separated from any signal due to said other longitudinal flux in processing by said frequency selective means.

9. A torque transducer as claimed in Claim 8 in which said flux generating means operates in a pulsed mode.

10. (Amended) A torque transducer element as claimed in Claim 7 in which said flux generating means comprises a pair of spaced coils wound about said shaft and between which said portion is situated and means for energising said coils at the selected frequency.

11.(Amended) A torque transducer element as claimed in Claim 7 in which said flux generating means comprises a magnetic structure having a pair of spaced poles which magnetically coupled to said shaft and between which said portion is situate, at least one coil would on said magnetic structure, and means for energising said at least one coil at the selected frequency.

12. (Amended) A transducer assembly for measuring, preferably in a non-contacting fashion, torque in a rotating shaft, the assembly comprising an erase head for cleaning a zone of the shaft as it rotates, a write head downstream of the erase head in the direction of rotation to write a magnetic track of a given width onto the cleaned zone, a pair of read heads spaced in an axial direction to respond to the magnetic track, said read heads being disposed on, toward or adjacent opposite sides of the track to generate respective signals, and differential means response to said respective signals to provide a signal dependent on the torque in the shaft.

13. (Amended) A transducer assembly as claimed in Claim 12 in which said write head is energised with an AC signal at a selected frequency.

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TORQUE MEASUREMENT APPARATUS

FIELD OF THE INVENTION

The present invention relates to the measurement of torque generated in a drive shaft. More particularly, it concerns the non-contacting measurement of such torque using magnetised transducers and seeks to compensate for, eliminate or avoid the effects of interfering magnetic fields.

BACKGROUND TO THE INVENTION

There have been prior proposals to use magnetised transducer elements for torque measurement, the transducer elements being a ring attached to a torqued shaft or the shaft itself. In this connection reference is made to U.S. Patents 5351555, 5465627 and 5520059 and to published PCT Applications WO99/21150, WO99/21151 and WO99/56099. In these specifications the ring or shaft is of magnetoelastic material circumferentially magnetised, that is the magnetisation forms a closed loop around the shaft. While such transducer elements are usable in the practice of this invention, other patterns of magnetisation are usable and do not necessarily rely on magnetoelasticity, and other shapes of transducer element may be employed. One other pattern of magnetisation which may be employed in the practice of this invention longitudinal magnetisation of the transducer region. One form of longitudinal magnetisation is disclosed in International patent application PCT/GB00/03119 filed 14th August 2000 and published under the number WO/

It is a feature of transducers systems employing magnetised transducer elements of the kind outlined above, that the torque dependent field component provided by the transducer element can be sensed by one or more sensors

adjacent to but not in contact with the transducer elements. Non-contacting sensor arrangements are of particular value in torque measurement on rotating shafts.

The above techniques are based on magnetic principles and therefore can be affected by other interfering magnetic fields, like the earth's magnetic field or fields generated by electric motors for example. In some environments where it is desirable to measure shaft torque, very strong magnetic fields may be present, particularly in the longitudinal axis of the sensing system. A typical application of this nature is the extended axis of an electric motor having a shaft projecting from the motor.

SUMMARY OF THE INVENTION

The present invention is predicated on a number of different approaches. A first may be broadly expressed as compensating or counteracting an interfering magnetic field. A second may be broadly expressed as a selective signal approach, particularly by introducing a frequency selective element into the torque-dependent magnetic flux to be measured that enables it to be distinguished from signals due to an interfering field. A third approach is to turn the "interfering" magnetic field to use and employ it as a source field from which to obtain a torque-dependent component. A fourth approach is a new way of measuring torque to which a frequency selective element may be applied. It is possible to use combinations of these approaches, particularly in combining the first approach with the second or third.

One implementation of the present invention according to the first approach above-mentioned provides a torque transducer for measuring torque in a rotating shaft of the kind having a transducer region in which a magnetic

transducer field is established and at least one non-contacting sensor adjacent the transducer region to develop a torque-dependent signal, wherein in operation the shaft is subject to longitudinal flux generated by means external to the transducer region, characterised by means magnetically coupled to said shaft to generate a compensating flux to counteract said longitudinal flux at the transducer region.

Preferably, the means coupled to the shaft for generating the compensating flux comprises at least one current-carrying coil about the shaft. It may comprise a pair of axially spaced coils between which the transducer region is situate. In the alternative or additionally, a magnetic structure may also be provided which has poles axially spaced along the shaft and at least one coil is wound about said magnetic structure.

An implementation of the invention according to the third approach above-mentioned provides a torque transducer for measuring the torque in a rotating shaft which, in operation, has a longitudinal field extending therealong, wherein at least one sensor is placed in non-contacting fashion adjacent a portion of the shaft to sense and provide a signal dependent on a transverse component of flux arising from the longitudinal flux in response to the torque in the shaft. More specifically a transverse component is transverse to the axis of rotation and at the surface of the shaft portion is usually detected as a component in the circumferential or tangential direction. In the preferred embodiment, at least one further non-contacting sensor is mounted to sense the longitudinal flux to provide a reference signal dependent thereon against which to measure the transverse component for use in obtaining a value for the torque in the shaft.

In yet another implementation of the invention, this time

in accord with the second, selective signal approach above-mentioned, a torque transducer for measuring the torque in a rotating shaft includes a portion or region of the shaft which acts as a transducer element and which is disposed between a pair of coils encircling the shaft and connected to induce a longitudinal magnetic field through the transducer region upon energisation of the coils. The coils are connected to an AC source, preferably a pulsed source, operating at a selected frequency so that the transducer region is subject to a magnetic field of alternating polarity. A sensor arrangement is responsive to a torque-dependent component of the alternating magnetic field and provides an AC output processed in a frequency-selective manner linked to the source frequency to extract the wanted component from any other noise (DC or AC) that may be present. The frequency-selective processing may be by way of a hardware or software implemented filter operating at the selected frequency linked with the AC source to synchronize the filter frequency to the source frequency. A synchronous detection scheme can be used detecting the sensor output signal with the aid of the AC source output to provide an inherent filtering operation.

According to another implementation, a transducer assembly for measuring, preferably in a non-contacting fashion, torque in a rotating shaft, comprises an erase head for cleaning a zone of the shaft as it rotates, a write head downstream of the erase head in the direction of rotation to write a magnetic track onto the cleaned zone, said track having a given width, a pair of read heads spaced in an axial direction to respond to the magnetic track, said read heads being disposed on, toward or adjacent opposite sides of the track to generate respective signals, and differential means responsive to said respective signals to provide a signal dependent on torque in the shaft. It is preferred to energise the write head with an AC signal,

preferably a pulsed signal, to detect the AC outputs of the read heads derived from the AC modulated track. The detection can be done in a frequency-selective manner to enhance discrimination from other signal fields that may be present. It is preferred that the write head be oriented with the head gap in the circumferential or tangential direction.

Aspects and features of this invention are set forth in the claims following this description.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will now be described by way of example and with reference to the accompanying drawings wherein:

Figures 1 to 3 illustrate measurement of shaft torque using circumferential magnetisation;

Figures 4 and 5 illustrate measurement of shaft torque using longitudinal magnetisation;

Figure 6 shows the longitudinal magnetic flux developed in the shaft of a typical electric motor;

Figures 7 and 8a show apparatus for cancelling an interfering magnetic field generated by an electric motor according to a first embodiment of the invention;

Figure 8b is an end view of the shaft shown in Figure 8a;

Figures 9a and 9b show side and end views of a shielded and actively compensated transducer in accordance with a second embodiment of the invention;

Figures 10a and 10b show side and end views, respectively, of apparatus for measuring shaft torque using a magnetic

field in the shaft according to a third embodiment of the invention;

Figure 11 shows a deflected magnetic field in the shaft of Figure 10a;

Figure 12 shows an arrangement for eliminating the effects of an interfering magnetic field by using a transducer system operating at a selected frequency in accordance with a fourth embodiment of the invention; and

Figures 13a and 13b show side and end views of an arrangement for measuring shaft torque using magnetic erase, read and write heads adjacent a shaft, according to a fifth embodiment of the invention.

Figures 1 to 3 illustrate detection of shaft torque using the technique of circumferential magnetisation referred to above. Fig. 1 illustrates the circumferential field, indicated by arrow, 2 under no torque condition in a transducer region 3 of a shaft 4 rotatable about axis A-A. Fig. 2 illustrates the closed loop nature of the field in a surface adjacent zone of the region shaft 3. The region 3 exhibits magnetoelasticity. Under "no torque" the circumferential field 2 in region 3 is entirely contained in the region 4: there is no external fringe field. Under torque, as seen in Fig. 3 the field 2 is skewed to produce an axially-directed North-South (NS) magnetisation whose polarity and magnitude are dependent on the direction (clockwise or counterclockwise) of the torque and its magnitude. The axial magnetisation emanates an external fringe field dependent on torque which is measurable by a sensor 7, or more usually by a sensor arrangement comprising a plurality of sensors. The sensor(s) may be of the Hall-effect or magnetoresistive type but preferably are of the saturating core type connected in a circuit such as disclosed in published PCT application WO98/52063.

Figures 4 and 5 demonstrate detection of shaft torque using longitudinal magnetisation of a region 3′ of the shaft 4. The region 3′ is of magnetic material. The longitudinal field 8 lies along the shaft in a surface adjacent annulus forming a torus of magnetic flux which closes mainly in an inner zone of the regions 3′ to form a closed toroidal loop. The surface field all lies in the same direction. There is a small quiescent longitudinal fringe field 10 that leaks from the shaft as seen in Fig. 4. In the form of longitudinal magnetisation being discussed, under torque, the field 2′skews (Fig. 5) as indicated by the dashed arrows 2"and produces a small transverse or circumferential component detectable by sensor 22: the longitudinal component is detectable by sensor 21. The sensors of the types already mentioned have directional responses and are oriented to be responsive to the desired field component.

Further information on the form of longitudinal magnetisation discussed above and the means of producing it is found in International patent application PCT/GB00/03119 (WO) which is incorporated herein by reference.

Attention can now be given to problems which arise when the shaft 4 is driven, and thus put under torque by a machine such as an electric motor.

An electric motor 63 is diagrammatically shown in Fig. 6. It has an integral output shaft 61 which is susceptible to providing a path for magnetic forces generated by the motor during its operation. Depending on the specific design of the motor and of the shaft 61 driven thereby some magnetic field can exit the motor assembly (unintentionally or inadvertently) through the drive shaft 61 of the motor 63 as indicated by arrows 60. This assumes the shaft is of a ferromagnetic material and is

capable of supporting a transducer region of the kind described above in an integral portion of the shaft.

When trying to measure the mechanical torque generated by the electric motor 63 in the shaft 61 by using the methods described above with an appropriate transducer assembly 62 which includes a magnetised transducer region 64 of shaft 61, the motor induced longitudinal magnetic flux 60 present in the transducer region 64 of drive shaft 61 can generate large sensor offset signals. The drive shaft itself provides the magnetic sensor host for the transducer region. These offset signals are modulated by the changes of the mechanical load on the motor axis and the supplied electrical current to the motor. The offset is therefore dynamic and cannot be easily compensated for.

A solution to the problem explained with reference to Fig. 6 is seen in Fig. 7. A pair of coils L1 and L2 are axially spaced about transducer region 64 and they are energised to provide a longitudinal magnetic field in region 64 that counteracts the field due to the motor 63.

As indicated in Fig. 7, the level of the interfering magnetic field strength may be measured in real time by an axially oriented sensor (such as sensor 7 or 21) forming part of the transducer assembly 62 and controlling a compensating current source 65 that energises coils L1 and L2 connected in series with a current I of a magnitude to cancel the motor induced field 60.

To allow measurement of longitudinal (axially-directed) field components of the transducer region, the compensating action can be set up under no torque conditions for circumferential magnetisation, then held at that value. Otherwise the adjustment can be done manually to establish a preset current value. The technique most

suitable will depend on the circumstances of each individual installation.

Figs. 8a and 8b illustrate a preferred implementation of the active compensation technique of Fig. 7. These figures show a collar structure which finds application in various other embodiments of the invention described below. In Figs. 8a and 8b the shaft 61 is collared at 20 to produce a recess 25 the base of which extends about transducer region 64 and which aids in causing internal longitudinal flux to "leak" externally to the shaft and be detectable. The external longitudinal flux is detected by sensors 24 which may be in controlling a current generating means for energising coils L1, L2 to counteract the external longitudinal flux as previously described and/or as part of the torque measurement process. If the region 64 is longitudinally magnetised torque is measured using sensor 23 (preferably a pair of diametrically opposed sensors) to detect a torque-dependent component of the external flux. In Fig. 7 the transducer region 64 lies between coils L1 and L2 within the sensor arrangement which is adjacent to but does not contact the shaft. Similarly in Figs. 8a and 8b the magnetised transducer region is located in the region forming the base of recess 25 with non-contacting sensors 23 and 24. The collar structure is applicable to a transducer region circumferentially or longitudinally magnetised. In Figs. 8a and 8b the sensor arrangement is appropriate to longitudinal magnetisation.

Figures 9 and 9b show an arrangement similar to that of Figures 7 and 8 in that it seeks to back off or nullify the motor leakage flux in shaft 61. It is intended for higher levels of flux. L1 and L2 are energised as before, for example in dependence on the flux sensed at 24. A housing 70 of magnetic material providing a magnetic shield encloses the transducer region 64 of the shaft 61

and the adjoining coils L1, L2. The shield 70 is apertured at 72a and 72b for passage of the shaft and these apertures provide axially-spaced, magnetic poles of opposite polarity between which the collared region 64 is located. The poles act on the shaft 61 to induce a longitudinal flux through the transducer region 64 to counteract longitudinal flux in the shaft due to the driving motor. The poles 72a, 72b are magnetised by one or more coils wound about the housing 70. Specifically a pair of coils L3 and L4 are shown and L3/L4 are energised by current I' dependent on the flux sensed by 24. The poles concentrate the shield flux. The polarity induced is the same as the coils L1 and L2. For a small shaft diameter the magnetic shield and coil L3/L4 structure enables higher ampere turn ratings to be accommodated for large leakage fluxes. The combination of L3/L4 and shield on one hand and the coils L1/L2 on the other may be applied separately. The shield arrangement may be advantageous when there are other stronger sources of stray magnetic field in the vicinity of the transducer. For example the shield may protect the transducer from fields of the order of 100 or more Gauss, whilst coils L1 and L2 typically protect against fields of the order of tens of Gauss.

A different approach is adopted in the apparatus of Figs. 10a, 10b and 11. Rather than nullifying the longitudinal flux from motor it is instead used as the transducer flux source in a longitudinal magnetisation type measurement. Here again a collared structure 20 aids in outwardly deflecting the longitudinal flux in the region 64 for producing a longitudinal (axial) directed external field. The longitudinal sensors 24 measure the longitudinal flux (of whatever value). The transverse sensor(s) 23 measures the circumferential component. The torque calculation is made independent of the actual flux in the shaft by using this as a reference. The measurement from sensors 24 is

used as a reference against which the torque-dependent component value from sensor(s) 23 is measured.

The axial component (measured by 24) is used to determine the maximum available field strength to measure torque at the sensor region. The result of this measurement is used to control the gain of processing circuitry for providing a signal representing torque. The greater the longitudinal magnetic field 60, the higher the sensitivity of the magnetic field measured by the circumferentially arranged magnetic field sensors. Therefore the amplification gain in the signal conditioning electronics for the circumferentially magnetic field sensors need to be reduced in proportion to an increase in the longitudinal magnetic field.

As shown in Fig. 11, the longitudinal field 60 that extends through the region 64 will be deflected as indicated at 60a in relation to the applied torque forces on the drive shaft 61. The whole shaft effectively acts as a force sensor. The greater the torque, the larger the circumferential component of the field, measured by sensor 23.

In the embodiments of Figure 7 and Figures 8a and 8b, the current in coils L1 and L2 is applied so that the loop fields compensate or nullify the interfering field. A similar coil arrangement to that illustrated in Fig. 7 and in Figs. 8a and 8b can be used in a different way in a technique which aims to eliminate the effect of the interfering field from the torque-sensing operation rather than cancelling or compensating the interfering field. This is illustrated in Fig. 12.

In Fig. 12 the coils L1 and L2 are not energised in dependence on a sensed field but to the contrary are energised to create a field distinguishable from

interfering fields. To this end the coils L1 and L2 are connected to an AC source 30, preferably a pulse-type source, to induce an alternating magnetic field in the transducer region 32 between the coils. This is a longitudinal field. The source frequency should avoid a relationship with main supply frequencies (50 or 60 Hz) or any other frequency imposed by the operation of the motor or machine with which the shaft is associated. Conveniently the source frequency is in the audio range, say between 500 Hz and 10 kHz. A frequency around 1 kHz would be suitable. It is also a frequency within the sensing capability of saturating-core type of sensors. Hall effect or magnetoresistive types of sensor may be expected to have a higher frequency response but frequency limitations may also be imposed in driving the coils L1 and L2.

The alternating magnetic field provides an alternating torque-dependent component at the source frequency sensed by the sensor(s) 23. The total torque-dependent component to which sensor(s) 23 responds may include a DC component from a machine-induced interference field or another AC component associated with the main frequency or a frequency emanating from the motor driving the shaft. The wanted source frequency component is extracted from the unwanted noise components by a filter 34 feeding or included within signal-processing unit 38 from which the torque representing signal T is obtained. The filter 34 may be realised in hardware or software and the filter frequency driven from the source as indicated by the chain line 36 to ensure the filter tracks the source frequency. Synchronous detection in which the detector is drive by a signal from source 30 may be employed. All these techniques are well-known.

The sensors (24) can be used to derive a reference signal for deriving the torque from the torque-dependent

component provided by sensor 23. The reference signal in this case is a component at the source frequency and is subject to filtering at 31 in the same way as the torque-dependent component is filtered. To this extent operation is similar to that of the embodiment of Figs. 10a, 10b and 11.

Another approach to torque measurement is illustrated in Figs. 12a and 12b. As the shaft 61 rotates a circumferential band 16 is cleaned by a magnetic erase head(s) 12 of the kind used in magnetic recording. Following the erase head (downstream), a write-head 13 writes a magnetic track 15 (of any kind) of width w. The shaft should preferably be rotating at at least 100 rpm when using this technique. The write-head 13 is oriented to have the head gap transverse to the axis of rotation of the shaft and preferably perpendicular to the axis of rotation so that the gap lies tangential or circumferentially disposed with respect to the rotating shaft surface.

The two read-heads 14a and 14b are spaced relative to the width w to give no signal when the shaft is barely rotating or known balanced signals that can be nulled. As torque builds in the shaft it has been found that the signals from the read-heads 14a and 14b become unbalanced to an extent dependent on the value of the torque. This reaction to torque is as if the magnetised track 15 or the flux associated with it is slightly deflected one-way or the other dependent on direction of rotation to produce an unbalance output from the read-heads 14a and 14b that is a measure of torque.

The write-head 13 may preferably modulate the track 15 in some way to provide a signal at each read head that can be separated from noise. To this end the write-head can be energised with a pulse waveform at a given frequency.

Filtering at the source frequency is applied to the read-heads 14a and 14b. This frequency-selective mode of operation is similar to that described for the embodiment of Fig. 12., The read pulses in Fig. 13 will be delayed with respect to the write pulses to an extent which is usable as a measure of the rate of rotation.

CLAIMS

1. A torque transducer for measuring torque in a rotating shaft (61) of the kind having a transducer region (64) in which a magnetic transducer field is established and at least one non-contacting sensor (23, 24) adjacent the transducer region to develop a torque-dependent signal, wherein in operation the shaft is subject to longitudinal flux (60) generated by means (63) external to the transducer region (64), characterised by and means (65) magnetically coupled to said shaft (61) to generate a compensating flux to counteract said longitudinal flux at the transducer region (64).

2. A torque transducer as claimed in Claim 1 further comprising means (24) for sensing and providing a signal dependent on said longitudinal flux, the means (65) for generating the compensating flux being responsive to said signal.

3. A torque transducer as claimed in Claim 1 or 2 wherein said means for generating the compensating flux comprises at least one current-carrying coil (L1, L2) about the shaft to be magnetically coupled thereto.

4. A torque transducer as claimed in Claim 1 or 2 said means (65) for generating the compensating flux comprises a magnetic structure (70) having poles (72a, 72b) spaced along the shaft (61) and at least one current-carrying coil (L3, L4) wound on said magnetic structure (70).

5. A torque transducer for measuring the torque in a rotating shaft (61) which, in operation, has a longitudinal field (60) extending therealong, wherein at least one sensor (23) is placed in non-contacting fashion adjacent a portion of the shaft to sense and provide a signal dependent on a transverse component of flux arising from the longitudinal flux due to the torque in the shaft (61).

6. A torque transducer as claimed in Claim 5 in which a further non-contacting sensor (24) is mounted to sense the longitudinal flux to provide a reference signal

dependent thereon for use in obtaining a value for the torque in the shaft.

7. A torque transducer for a rotating shaft (61) comprising flux generating means (L1, L2) for generating a magnetic flux extending longitudinally in a portion (64) of the shaft, said flux generating means (L1, L2) being magnetically coupled to said shaft at axially spaced locations between which said portion (64) is situated, at least one sensor (23) placed in non-contacting fashion adjacent said portion to provide a signal dependent on a transverse component of flux arising from the longitudinal flux in said portion (64) due to the torque in the shaft (61),

said magnetic flux generating means being operable to generate an alternating magnetic field at a selected frequency, and said at least one sensor signal being processed by frequency selective means (34) operable at said selected frequency to provide a signal representing torque in the shaft (61) derived from said alternating magnetic field.

8. A torque transducer as claimed in Claim 7 in which said shaft (61) transmits in operation another longitudinal flux (60), not generated by said flux generating means (L1, L2: L3, L4) said selected frequency enabling the signal dependent on the transverse component of flux to be separated from any signal due to said other longitudinal flux in processing by said frequency selective means (34).

9. A torque transducer as claimed in Claim 8 in which said flux generating means operates in a pulsed mode.

10. A torque transducer as claimed in Claim 7, 8 or 9 in which said flux generating means comprises a pair of spaced coils (L1, L2) wound about said shaft (61) and between which said portion (64) is situated and means (30) for energising said coils (L1, L2) at the selected frequency.

11. A torque transducer as claimed in Claim 7, 8 or 9 in

which said flux generating means comprises a magnetic structure (70) having a pair of spaced poles (72a, 72b) which magnetically coupled to said shaft (61) and between which said portion (64) is situate, at least one coil (L3, L4) would on said magnetic structure, and means (30) for energising said at least one coil (L3, L4) at the selected frequency.

12. A transducer assembly for measuring, preferably in a non-contacting fashion, torque in a rotating shaft (61), the assembly comprising an erase head (12) for cleaning a zone (16) of the shaft as it rotates, a write head (14) downstream of the erase head (12) in the direction of rotation to write a magnetic track (15) of a given width onto the cleaned zone (16), a pair of read heads (14a, 14b) spaced in an axial direction to respond to the magnetic track (15), said read heads (14a, 14b) being disposed on, toward or adjacent opposite sides of the track (15) to generate respective signals, and differential means responsive to said respective signals to provide a signal dependent on the torque in the shaft (61).

13. A transducer assembly as claimed in Claim 12 in which said write head (13) is energised with an AC signal at a selected frequency.

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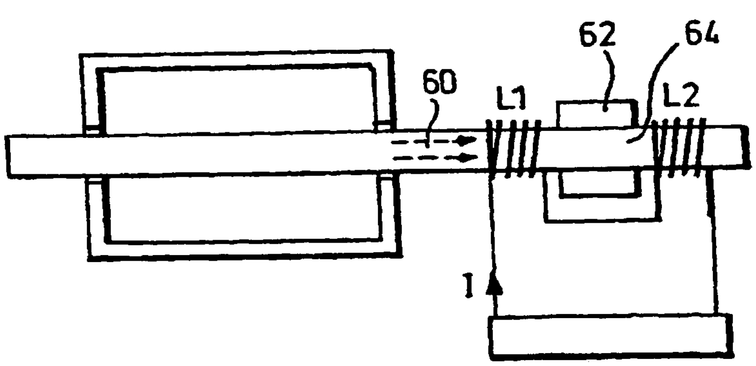
(54) Title: TORQUE MEASUREMENT APPARATUS



(57) Abstract: Torque in a shaft (61) is detected by means of non-contacting sensors (23, 24) sensing a torque-dependent magnetic field emanated by an integral transducer region (64, 32) of the shaft (61) that is circumferentially or longitudinally magnetised. The shaft (61) is driven by a motor (63) and subject to a longitudinal magnetic field (60) which acts on interference field. In one implementation of the invention coils (L1, L2: L3, L4) are energised to provide a counteracting magnetic field to compensate the interference field (60).

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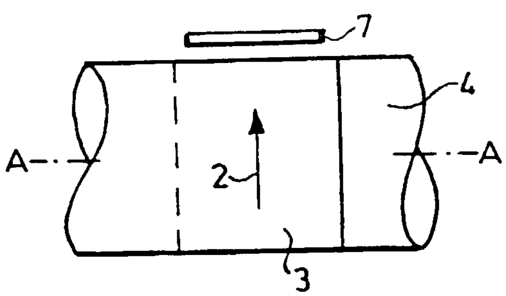

Fig.1.

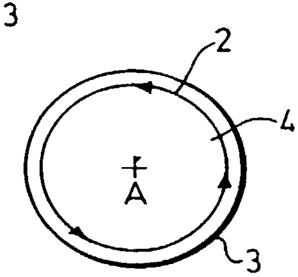

Fig.2.

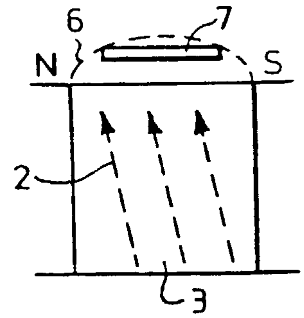

Fig.3.

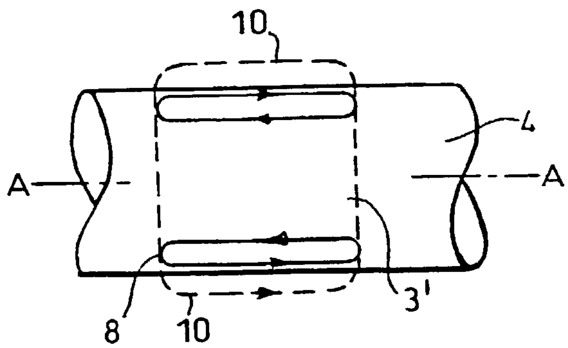

Fig.4.

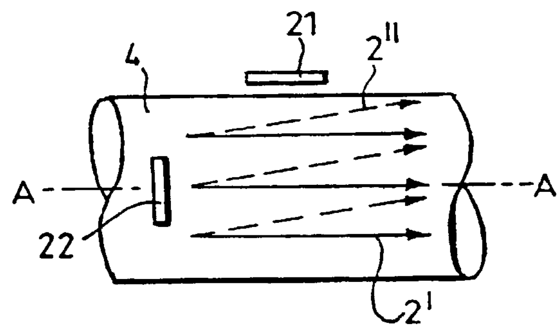

Fig.5.

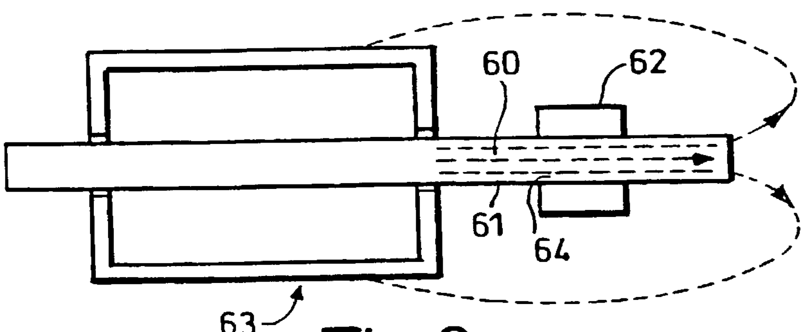

Fig.6.

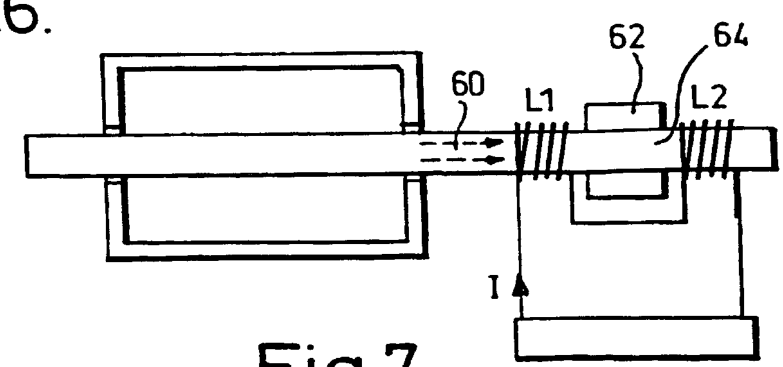

Fig.7.

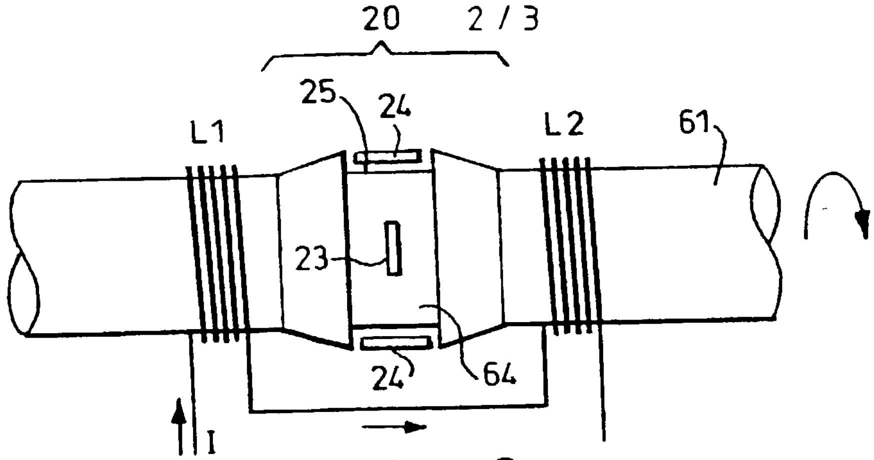

Fig.8a.

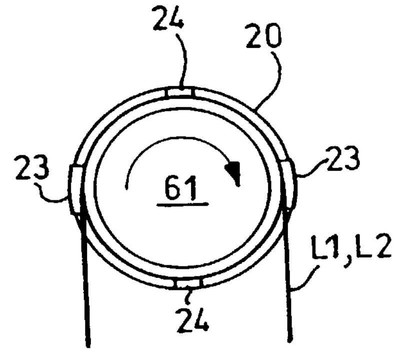

Fig.8b.

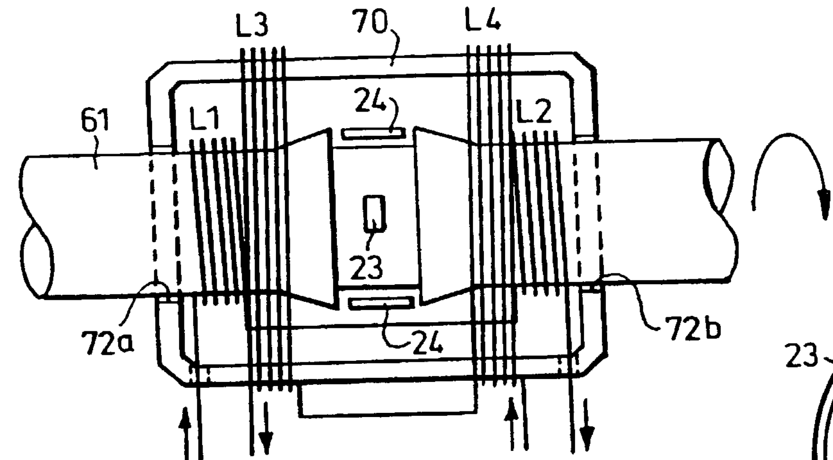

Fig.9a.

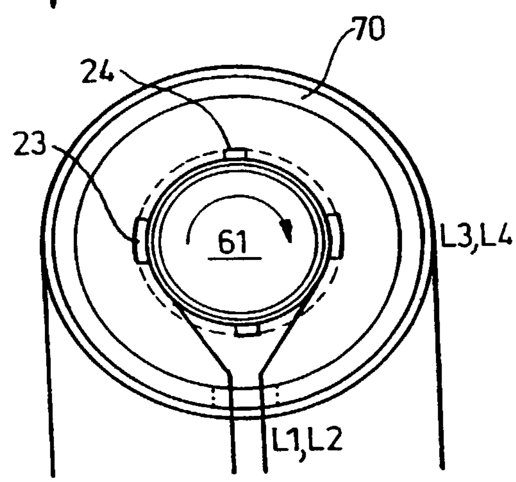

Fig.9b.

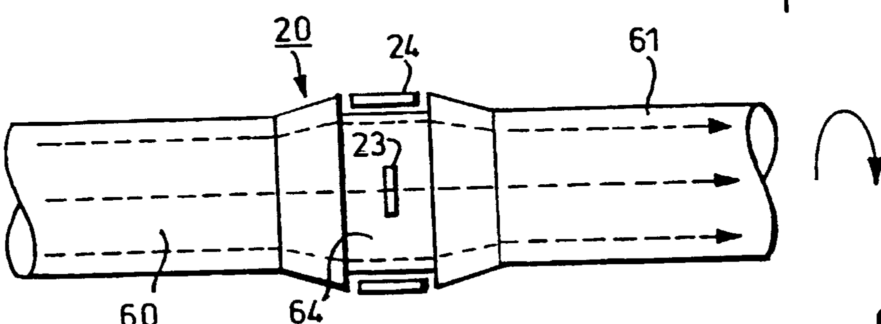

Fig.10a.

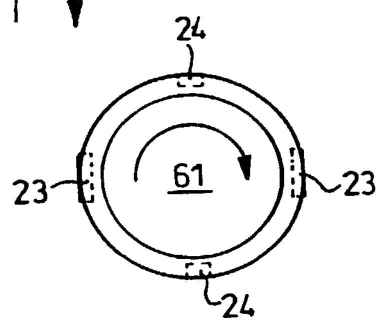

Fig.10b.

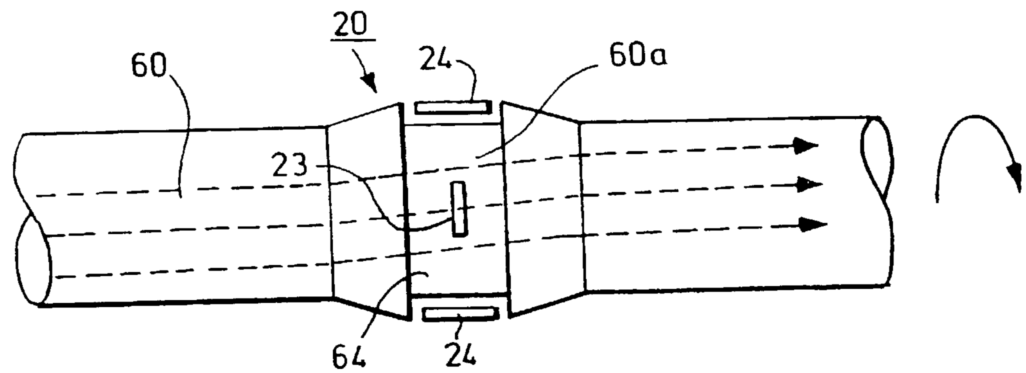

Fig.11.

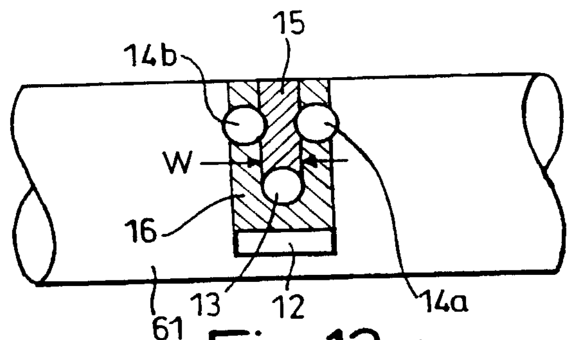

Fig.13a.

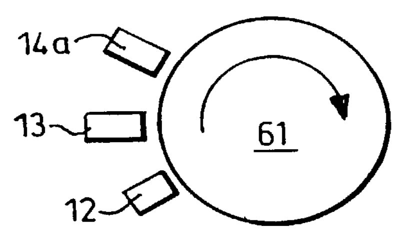

Fig.13b.

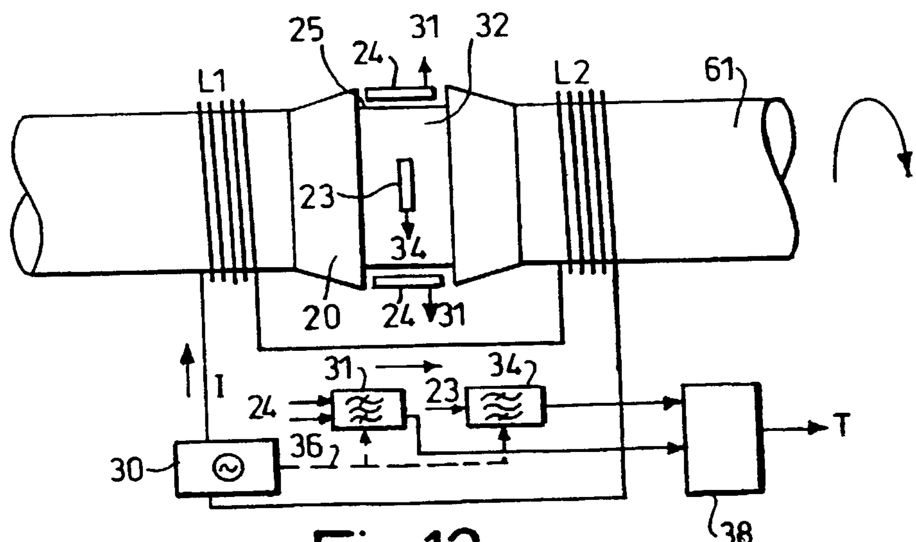

Fig.12.

OIPE JC144 JUN 1 4 2002 PATENT & TRADEMARK OFFICE

DECLARATION AND POWER OF ATTORNEY FOR PATENT APPLICATION

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name,

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled TORQUE MEASUREMENT APPARATUS the specification of which

(check one) ☐ is attached hereto.

☒ was filed on April 8 2002

as Application Serial No. 10/089,978

and was amended on ____________ (if applicable)

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, §1.56(a)

I hereby claim foreign priority benefits under Title 35, United States Code, §119 (a-d) or §365(b) of any foreign application(s) for patent or inventor's certificate, or §365(a) of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below any foreign application for patent or inventor's certificate, or any PCT international application having a filing date before that of the application on which priority is claimed:

Prior Foreign Application(s) — Priority Claimed

(Number)	(Country)	(Day/Month/Year Filed)	Yes	No
9924046.7	GB	11/10/99	☒	☐
PCT/EP00/10022	PCT	10/10/00	☒	☐

I hereby claim the benefit under Title 35, United States Code, §120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, §112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, §1.56(a) which occurred between the filing date of the prior application and the national or PCT international filing date of this application:

(Application Serial No.)	(Filing Date)	(Status) (patented, pending, abandoned)

I hereby claim the benefit under Title 35, United States Code, §119(e) of any United States provisional application(s) listed below:

(Provisional Application No.)	(Filing Date)
(Provisional Application No.)	(Filing Date)

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 18 U.S.C. 1001, and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

5-

POWER OF ATTORNEY: As a named inventor, I hereby appoint the following attorney(s) and/or agents to prosecute this application and transact all business in the Patent and Trademark Office connected therewith. Robert C Kain, Jr., Reg No. 30,648; Martin Fleit, Reg No. 16,900, Jon A Gibbons, Reg. No. 37,333; Jose Gutman, Reg. No. 35,171; and Steve Bongini, Reg. No. 40,917

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(Supply similar information and signature for third and subsequent joint inventors.)

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